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MANAGING SHARED UNDERSTANDING IN COLLABORATIVE DESIGN PROJECTS

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Abstract

This paper describes an empirical study in the field of product design. It focuses on far-reaching integration of different knowledge domains. Knowledge integration between actors requires the creation of shared understanding about the project content. This research project provides insight in the barriers and enablers for creating shared understanding between actors from different disciplines. It gave insight the key problems concerning the integration of different disciplines. We collected data by observing meetings and interviewing actors. The learning history method was used to analyze the data. The paper ends with a discussion about the results and managerial implications.

1. Introduction

Increasing product complexity requires a far-reaching integration of the different knowledge domains of the actors from different disciplines. Knowledge integration of actors from different disciplines is difficult for companies, because actors have different backgrounds, interests and perspectives on the new to develop product [1] [2], [3],[4], [5], [6].

For companies it is also difficult to get all actors thinking along the same line, because the interpretation as well as the understanding of each other’s information gathered is difficult [4], [7], [6]. The reason is that actors from different disciplines use different languages and different representations of the design, because they have different interests and responsibilities. Product specifications may contradict each other resulting in actors competing against each other. Negotiations and trade-offs are required to make the actors’ efforts coherent [4].

In this paper, we studied the process of creating shared understanding about the design content between actors with different knowledge domains. First, we did a literature study followed up by an extensive empirical study.

2. Problem definition

To describe the problem of knowledge integration between actors from different disciplines, Bucciarelli introduced the term 'object worlds'. Bucciarelli defined object worlds as: '*the domain of thought and artifact within which actors in engineering design move and live when working on any specific aspect, instrumental part, subsystem or sub function of the whole.*' [8]. An object world contains individual beliefs, interests, knowledge and experiences of an actor, as well as the methods and techniques he is able to use. Differences in object worlds of different actors may hamper effective cooperation, because actors with different object worlds communicate differently and about different things.

Next to Bucciarelli also other authors have introduced object world kind of concepts. Dougherty introduced the concept of *'thought worlds'*. According to Dougherty, a thought world is a community of persons engaged in a certain domain of activity who have a shared understanding about that activity [9]. Dougherty claims that: "*thought worlds with different funds of knowledge cannot easily share ideas, and may view one another's central issues as esoteric, if not meaningless. A thought world evolves as an internally shared system of meaning which provides a 'readiness for directed perception' based on common procedures, judgments and methods.*"

The main difference between thought worlds and object worlds becomes transparent by looking at the definitions. Object worlds belong to individuals and thought worlds to a department or functional group. Looking at a detailed level to communication between actors, thought worlds are not sufficient. This is because of the existence of the *habitus*, which means that not only does the objective knowledge of an actor make him act as he does, but also his experiences [10].

However, when you look at the traditional interface problems between departments, thought worlds are sufficient. This implicates that knowledge integration can occur on more than one level.

Since we are interested in the communication between actors from different knowledge domains, we will use these two levels of knowledge integration. The individual level is called *actor* level and the group level is called *company* level.

3. The role of shared understanding in design projects

From previous research, we know that the existence of object worlds and thought worlds hampers effective cooperation and the creation of shared understanding between actors; e.g. [7], [9].

To get more knowledge about shared understanding in product design projects, it is useful to see the product development processes as a social process, by using the definition of Weick and Roberts. Their definition reads; *a social process is a set of ongoing interactions in a social activity system from which actors continually extract a changing sense of self-interrelation and than re-enact that sense back into the system. This ongoing interaction process is recapitulated in individual lives and continues despite the replacement of people.* [11]. We think Weick and Roberts' theory is particularly applicable for design projects, because product design projects are the integration of organizational activities. According to Weick and Roberts, an actor executes three main activities during this social process. The first thing is the *construction* of the task an actor needed to do. Doing this an actor understands that his task is a part of a system and that others perform their tasks in this system. Therefore, an actor interrelates his action to the actions of others. This means that the relations between the actors are not predefined, but are constructed during the process and that actors are

dependent from findings of the other actors [11]. A result derived by an actor executing a development task may result in the necessity that another actor needs to make an iterative loop. A design team cannot prevent these loops, since they are the nature of developing.
However, iterative loops can also originate by mistakes in 'the extracting and re-enacting sense to the system'. These mistakes may cause that *shared frames* about the design content do not originate and that the tuning between the actors failed [12].
Mohamed and Dumville speak not about frames but of team mental models or shared mental. Team mental models are '*the actors' shared organized understanding and mental representations of knowledge about the key elements of the team's relevant environment*.' They claimed that actors have shared understanding if they have *cognitive consensus*. This refers to the similarity among the actors about how the key issues in de development process are conceptualized [13].
Mohammed and Dumville added that process related aspects are also important to the creation of shared understanding. They used the term transactive memory, which is *a set of individual memory systems, which combines the knowledge processed by particular actors with a shared awareness about who knows what*. Actors should not only be create shared understanding about the design content, but also about how the knowledge is processed and about who knows what. Transactive memory makes it possible to develop complex products with actors from different disciplines, without having too much redundancy of knowledge. In other words, effective transactive memory makes it possible that actors with different object worlds cooperate with each other. So, next to knowledge integration on the actor and company level, there is also tuning on the process level. This level is called *project level* and deals with project management factors.
The definition of shared understanding used in this research project combines the definitions of Valkenburg and Mohamed & Dumville: *Shared understanding is similarity of the (individual) perceptions of actors about how the design content is conceptualized or an effective transactive memory*. [12], 13].

As mentioned above, earlier research on shared understanding in product design teams has found that a lack of shared understanding caused unnecessary iterative loops in design projects [14], [15]. Ultimately, a lack of shared understanding reduces the quality of the final product, because in the end actors did not solve all problems. Therefore, effective communication is an elementary component of product design. Bucciarelli, Hill et al. and Kratzer supported this finding [7], [15], [16]. This is also in line with the study of Moenaert and Souder who found that the success and failure of product design related to the (in) effectiveness of information processing [6].
Song et al., in their study, added that the highest quality products came from teams with an increase in shared understanding [17]. Of course, at the end of the process the amount of shared understanding must be reasonable high. This finding implicates, that the process of creating shared understanding, might be more important, than having shared understanding. When there is no shared understanding at the start of a product design project, actors need to discuss the issues on hand and people have to learn from each other. Therefore, diversity of thoughts at the beginning of a product development project, often leads to innovations [3], [6], [18]. This is an explanation for the high quality products, produced by multidisciplinary teams with an increase in shared understanding. The explanation Weick and Roberts gave for this phenomenon, is that groups are smartest in their early stages, because in the end of the project teams loose mind and interrelating between the disciplines becomes more routine, more casual and more automatic, which reduces the quality of the interaction [11].

Previous research showed us that the *creation* of shared understanding is important, to be able to manage the integration of different knowledge domains and to develop qualitative products.

Bucciarelli and Dougherty showed us that the *achievement* of shared understanding is difficult, due to the existence of object worlds and thought worlds. However, what these studies do not describe which factors hamper or stimulate the achievement or creation of shared understanding.

4. A previous research project

Earlier, we looked at factors that undermine or stimulate the achievement of shared understanding between actors [19]. We called stimulating factors enablers and undermining factors barriers. The product design project studied had just finished, so it was a retrospective for the actors involved. We collected data by means of interviews and desk research. We did seven cases in one company. The cases were analyzed, compared, and evaluated, according to the learning history method [20]. The results of this previous study, showed two patterns. First, we found that enablers and barriers exist on the three levels derived from literature: the actor, project and company level. The *actor level* belongs to an individual actor within the company. Barriers and enablers on this level occur, due to the existence of object worlds. Barriers and enablers on the *company level* occur due to the existence of thought worlds. The integration of the knowledge of the different disciplines in a company caused these barriers and enablers. Barriers on the *project level* are process related and have to do with the effective use of transactive memory. They refer to project management factors like time, money, quality etceteras. Table 1 shows examples from each category.

Level:	**Barrier**	**Enabler**
Actor	The developer does not know how to interpreter the information from Marketing.	The mechanical engineer is able to read the drawings of the electrical engineer.
Project	Gate three is passed without reaching the quality level.	Due to the dedication of extra manpower, all development problems were solved in time.
Company	The development department is 80 km from the production plant	All actors are located in one building.

Table 1: Examples of barriers and enablers on the three organizational levels

The second pattern found was that barriers and enablers formed together in six themes, each representing a specific problem, like the cooperation with suppliers, the interface between Development and the rest of the organization and the implementation of new technology. Combining the two patterns shows that within the themes, enablers and barriers exist on more than one level. So, enablers and barriers on the three levels are interrelated. To optimize product design projects, by making the achievement of shared understanding easier, barriers should be resolved integrally and the actors should preserve enablers.

The study presented in this paper, is an extension of our previous research. Instead of looking at which factors influence *the achievement* of shared understanding, we looked at the stimulating and hampering factors for *the creation* of shared understanding. Additional, we derived themes representing the project content, as done in the previous study. To be able to get insight in the creation of shared understanding, we executed an extensive real time case study in practice.

5. Research method

The empirical study done is about a product design team, who was responsible for the development of tunnel installations of the Dutch High speed train from Amsterdam to Brussels, which is a large-scale one of product. They developed, for example, the elevators, the vans and the escape doors in the tunnels at the route. All tunnel installations have to function together (in the case of an accident), so collaboration was an important factor in this development project. Since there were eleven technical subsystems many different disciplines were involved in the team, which made this project also interesting to observe. The product design team observed was part of a consortium, which is responsible for the superstructure of the route and the future maintenance of the infrastructure.

Looking at the product design team observed one could not speak of *the* development team. The team was a collaborative team hierarchy, from which structure originates from the new product's architecture [21].

The team observed consisted of three different kinds of sub teams, showed in Figure 1. The first team was the *homogeneous development team* that developed a technical subsystem, as the teams on the level of the Control department of Figure 1. The product design project studied consists of eleven of these teams. The second team is the *system engineering team* with representatives from the homogeneous development teams together with two system engineers. This team integrates the eleven subsystems to a whole. The third team is the *multidisciplinary management team*; also named core team. Besides representatives from the homogeneous development teams, also actors from Quality, V&V (Validation and Verification), RAMS (Reliability, Availability, Maintainability and Safety), Occupational Health & Safety and Procurement were in the core team. The core team planned and monitored all activities needed to develop the new product. Together, the product design team studied consisted of about 60 actors, at the time of this study.

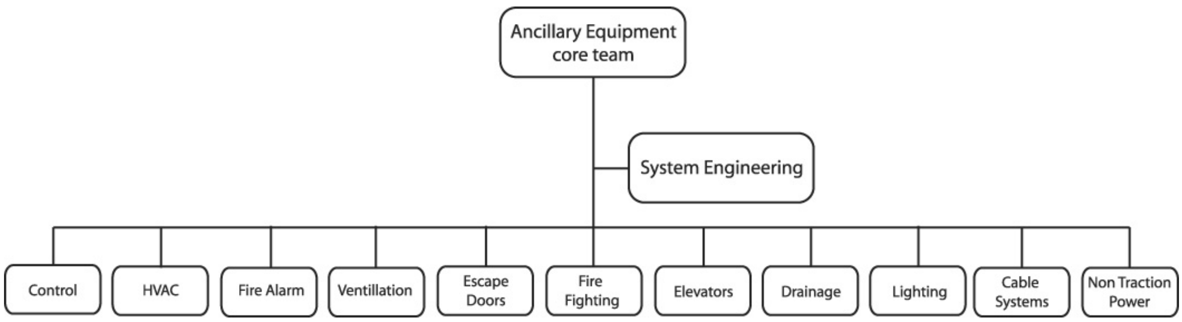

Figure 1: The structure of the product design team observed

The fieldwork conducted took about four months. We used the first month to get enough knowledge to be able to understand the project and to decide to follow what aspects. The next six weeks were the actual data collection period. The last one and a half month was used to read some additional reports and to follow how certain aspects evolved. During the six weeks of the main data collection, we were present in the company for two or three days a week.

Data collection

The interest of this research project was the creation of shared understanding during product design. To measure this, it was important to observe communication between actors with different object worlds. To do this, we observed three kinds of meetings of different engineering teams.

The first team meeting chosen was the Progress Meeting of the core team, which was weekly. This team represented all disciplines involved in the product design project. The Progress meeting had a strict agenda including the following items: Comments on Minutes of the last meeting, Actions, Management Announcements, Accommodation and IT related items, Progress of the work packages, Risks and Miscellaneous.

During the Progress Meetings many subjects were discussed, (e.g. financial-, technical- and political issues). Since the research project concentrated on the design content, notes were made of the technical issues or issues who influenced cooperation and communication about the design content directly. We made this focus, because otherwise there came too much 'noise' in the data. Besides, for the researcher it should be almost impossible to catch all the information, because of time and knowledge constraints. In the Progress Meetings technical issues were named and controlled (so every core team member knows what plays and how much progress there is), but were discussed in more detail during the System Engineering Meeting, which followed directly after the Progress Meeting.

The System Engineering Meeting was the second meeting observed. During these meetings technical aspects were discussed between de 'owners' of the different subsystems. The chairman of the meeting was the System Engineer, who is the address point of the tunnel installation to the outside world. The System Engineering Meeting had an ad hoc agenda, which was drawn up during the week and during the Progress Meeting earlier that day.

The third kinds of meetings observed were Interface meetings between the subsystem Control and the other technical sub systems. The reason for choosing these meetings was that the control system (designed by Control) is responsible for the regulation and the control of all other subsystems. Therefore, Control needs to communicate intensively with the other subsystems about how the subsystems function together. The participants of these meetings were most of the time the lead engineers of Control and the lead engineer of the other subsystem involved. The agenda of the meetings were drawn up before the meeting. The subjects changed during the time. The first meeting with Control and other subsystems was rather informal and therefore not very structured. However, as more meetings followed, the meetings became more structured by going through the Minutes of Meeting of the meeting before.

During the meetings, actors communicated about different subjects and they created (shared) frames about these subjects. During the meeting, notes about their conversation were made. From the notes frames were detected, by looking at how the team went trough the subjects discussed. (For the method to detect frames, see [12].)

The observation method followed to detect frames was the same for all meetings. The actors were asked to ignore the researcher and meet as they normal do.

To verify whether actors really share the frames communicated, we interviewed the actors after the meeting. The choice of the actors interviewed was dependent of two criteria. First, we concentrated on the technical aspects; the design content. Therefore, we only interviewed the actors involved in technical issues. Second, the actors chosen were highly involved in the meeting. If an actor was involved in more than one meeting, we asked questions about all meetings he was involved in. To verify whether actors have shared understanding about the design content, actors we asked questions about how they think about the particular frame. For every frame, we interviewed more than one actor about this content.

In the observation period, two interview strategies were followed. First, we asked the actors detailed questions about what happened during the meeting. However, actors could not remember the exact situation anymore, which made the interviews annoying and not as useful as they could be. Sometimes it was because subject evolved further, but most of the time it was because the actors could not remember what exactly happened during the meeting. Therefore, we choose another strategy. We asked the actors about their opinion about a

particular frame. So, the content of the frame itself became more important, than the how it was discussed during the meeting. The first strategy questions were asked like: "*What did person X say about the coding concept*? And "*how did you react on that and why did you do that?*" During the second strategy, questions like: "*What do you think about the coding concept*?" were asked.
At the end of every interview, we asked the actors if more remarkable things happened during the week and if the actor had something more to say about cooperation and communication aspects. This last strategy led to usable interviews. Due to time constraints of the actors, the interviews took place one or two days after the meetings.
Besides the interviews, we did also desk research. Documents like minutes of meeting, presentations, project description documents, design philosophy documents were read, to verify the reliability of both the observations and the interviews.

In the six weeks of actual fieldwork, 12 meetings of 2-3 hours average were observed and 22 interviews were done with 18 actors. Besides, informal talks with all the actors were held, from which notes were made in a logbook.

Data analysis

To make transparent whether actors had shared understanding about the design content, the learning history method was used [20]. The learning history method provided a structured and transparent way of analyzing the cases [19]. The first step of the method was the transcription of the interviews. Combining the transcriptions of different actors about one frame creates a *jointly told tale*. A jointly told tale reflected on the frame from the actors' perspectives. From all 'jointly told tales' analyses were made. The analyses were put next to the 'jointly told tale' in a column. Putting the analysis next to the 'jointly told tale' provides transparency about how the data were analyzed. The jointly told tales, together with the analysis formed the learning history of this project. The learning history was used to check whether the actors had shared understanding or not. After that, we sorted all factors that influenced the creation of shared understanding. Clear statements about what really influenced the creation of shared understanding were formulated. The statements formed the barriers and enablers. The next step was the categorization of the barriers and enablers. The barriers and enablers were categorized according to their organizational level derived from literature; company, project or actor level. Categorization according to the organizational level was done by one researcher, since the method of coding was validated in the previous study [19].
Next to categorization on the organizational level, we clustered the barriers and enablers according to a central issue, which they referred to: a theme. The clustering was done in two steps. The first step was combining all barriers and enables within a frame. The second step was clustering the frames about the same (kind of) subject.
Within a theme we looked what barriers and enablers took place and how the design content developed, by making a description of the theme. The themes gave insight into the main problems with communication and into the relationship between the barriers and enablers.

To improve the validity of the study, besides the interviews multiple triangulation methods were used [22]. The first triangulation method used is the use of different data gathering methods. Additional to the observations and interviews, data were collected from project documentation, including presentations, minutes of meetings and design documents. This triangulation of methods provided us directly a triangulation of sources; notes, taped interviews, reports, PowerPoint presentations, etc. Besides common triangulation methods named by Yin, we also improved the validity of the data by presenting the data analysis to the respondents of the systems engineering team during two workshops in which the results found were discussed. This gave extra feed back about the quality of the interpretation of the data.

Yin also advises to create a case study database to increase the reliability of the data. He advises to make two separate databases: an evidentiary database and a report data base [22]. In this study several evidentiary data bases were made and besides also papers and reports were written and presentations were made.
Concluding, one can say that multiple sources of evidence and making the evidence transparent, guaranteed the reliability of the data. Several triangulation methods and the feedback of the respondents guaranteed the internal validity. One case study cannot test the external validity, but the first analysis of a parallel case study using the same research method showed similar results. This suggests that the external validity is sufficient.

6. Results

This section describes the results of the six-week observation period. From the data analyzed, it was possible to detect the barriers and enablers. 196 barriers and 102 enablers were found. The barriers and enablers were categorized according to the three organizational levels derived from literature: the actor, project and company level. We found 70 barriers on the actor level, 117 barriers on the project level and 9 barriers on the company level. We also found 35 enablers on the actor level, 60 enablers on the project level and 7 enablers on the company level. Table 2 shows examples of barriers and enablers on the three levels. The high amount of barriers and enablers on the project level can be explained by the fact that most actors interviewed (the lead engineers) have a project management task. These people were interviewed, because they have most interaction with actors from other disciplines. The low amount of barriers and enablers on the company level can be explained by the fact that the actors were dedicated to the project and that the project was done rather unattached by developments within the company.

Level:	**Barrier**	**Enabler**
Actor	The system engineer lost the feeling with the design due to the amount of management tasks he has.	The civil engineer developed a questionnaire, which helped her to understand the most important bottlenecks the lead engineers face with the division of the buildings.
Project	The monitoring process of the fans caused design changes, which cannot be traced directly.	The procurement process was efficient due to time restrictions.
Company	The move of the Control department to another building decreased the amount of communication between Control and the rest of the development team.	There is a System Engineering group established on the highest organizational level of the development project.

Table 2: Examples of barriers and enablers on the three organizational levels

Looking at Figure 2, one can see that the lead engineers (core team members) have indeed most barriers and enablers on the project level and engineers have most barriers and enablers on the actor level, which is similar to results from earlier research and to research done by Gerwin and Moffat. [19], [21] Next to barriers and enablers derived from both observations and interviews with the actors, also 16 barriers and 8 enablers were derived from only observation.

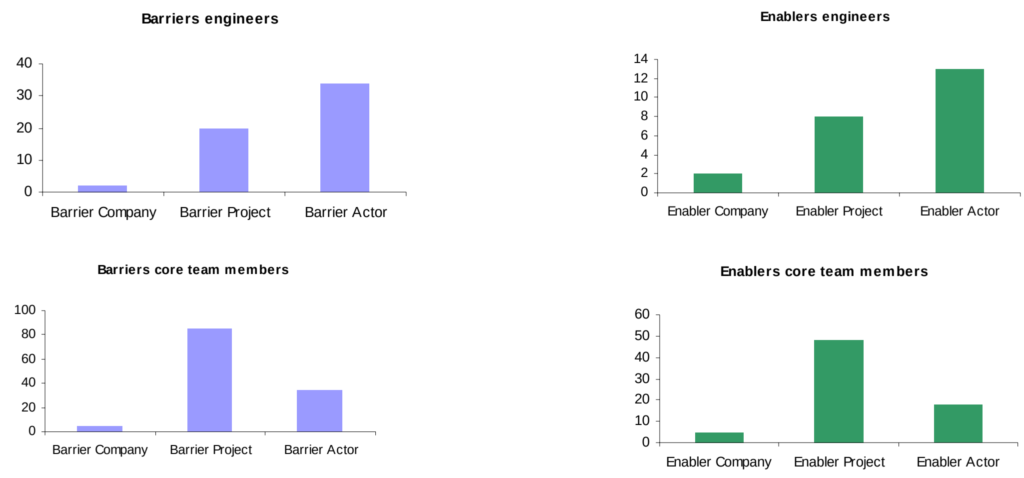

Figure 2. Barriers and enablers lead engineers and engineers

The last step of the data analysis was the clustering of the barriers and enablers according to their content. This resulted in five themes and a small category 'Other' (only five barriers and enablers).

Theme 1 concerns the internal *interfaces between actors from different homogeneous design teams*. The main problem between these homogeneous groups was that object worlds really have to integrate on all different levels. One technical subsystem had to function together with the other and the homogeneous design teams need (in time) detailed information about each other's work. In the team studied, the engineers had a waiting game attitude towards each other. They were not a team, but they operated from different 'islands'. The delivering party thought the receiving party had too vague questions about their subsystem and had an inadequate development plan. The receiving party, on their turn, thought the delivering party was running out of the planning. They also found the quality of the work done by the others not sufficient. There were also problems with delivering appropriate interface documents, because actors were familiar with these documents. The communication between two design teams was often jargon laden and therefore not always understood by all actors. Intensive interface meetings brought the parties closer together.

Theme 2 is the *interface with the consortium* and the team observed. The main problem with the interface with the consortium is the involvement of the Maintenance Company during development, which they not well organized. The Maintenance Company does not have the knowledge to be involved in the early stages of product design. They also miss the capacity to do the work. The input from Maintenance is necessary, because the consortium is responsible for both development and the maintenance of the project for an extensive period. Another problem in this theme is the apportionment of the different development tasks within the consortium.

Theme 3 is also external and covers *the interface with the outside world*. There were problems with external parties who have to deliver drawings for the product design team studied. The top management team of the consortium underestimated this interface. No pressure was put on this party to deliver the drawings, so they were not finished in time. The engineers from the external party were also not able to make drawings, which were useful for the product design team, since they were not familiar with these kinds of drawings.

Also, an external party was involved who had to approve the equipment developed. Information about what this party required was not given, since different actors within this party disagree about these requirements.

The interface with the suppliers of the technical equipment was well prepared and well performed. There were only some procedural difficulties.

Theme 4 is about *the communication infrastructure* between the different development teams. This infrastructure consists of two parts; oral and written communication. The oral communication formalized in meetings, but there is also informal communication between the actors. There was a weekly meeting of the multidisciplinary management team. This meeting was informative, but most of the time too long. The actors discussed too many points concerning the content of the technical sub systems, while only project progress was on the agenda. Another problem was that the actors did often not deal with actions that arise from the meeting in time. The meeting between the multidisciplinary development team was often cancelled, during the observation period, because the system engineer (who led this meeting) was often absent due to higher management tasks he had to do. Halfway the observation period they contracted a second system engineer to solve this problem. The meeting itself had an ad hoc agenda. This helped discussing the most urgent points. However, they also discussed less important points, because they popped up during the meeting. This went at the cost of the efficiency of the meeting.

The customer of this project strictly formalized the written communication in this project. The quality manager filed all documents in a database after a quality check. They also formalized the format of the documents in templates and they coded the drawings according to a coding concept. It was difficult for all actors to work according to both the templates and the coding concept, since they were not used to write and draw according to such strict rules.

Finally, we found Theme 5 named *the implementation of new processes*. The implementation of new processes consists of two subjects; the RAMS process, which guarantees the quality of the design and the Validation and Verification process of the requirements. Since RAMS plays an important role in the project, a separate RAMS team was set up. The interface between RAMS and the technical subsystems elapsed not fluently. The RAMS team does not know every detail from the subsystem and did therefore some impossible proposals. The engineers from the technical subsystems, on their turn, saw RAMS as an activity that caused problems and an amount of extra work. The result was that RAMS did not become an integral part of the design process.

Another quality tool is the V&V process of the requirements. The V&V manager made a plan to trace and test the requirements. Besides, he made a plan to track changes in the requirements. The engineers who had to execute the V&V plan were not involved in making the plan. The engineers had trouble to understand the plan and the procedures they had to follow. For one homogeneous design team the V&V plan came too late. They had to revise their project documentary concerning V&V, which cost much time.

Although there were some problems with RAMS and V&V, the quality of these two processes was sufficient, since the customer was satisfied.

7. Discussion and managerial implications

This section discusses the results found in this research project. First, the amounts of barriers on the three different organizational levels are discussed. Subsequently this section discusses the themes found.

The amount of barriers and enablers found in this study is about the same compared to a similar (not published) study done according to the same research method and during the same observation period. Comparing the proportions between the three categories (company, project and actor) of these two studies, they are also about the same.

However, comparing these proportions with the retrospective study of Kleinsmann and Valkenburg, there is a remarkable difference [19]. In retrospect, the amount of barriers on the actor level was higher than the amount of barriers on the project level. In the two real time studies done this was opposite. The explanation we give for this difference is that communication about the design content is seen (by the design research community) as the most difficult kind of communication to reach shared understanding on. Olsen et al. did a study about the kinds of communication in development projects, which showed that 20% of the design meeting is about planning and monitoring of the development process, 30% about progress and 40% about the design content. [23]. Their study showed that communication about the design content is the most substantial component of all communication. Therefore, Kleinsmann and Valkenburg started the retrospective case study interviewing the actors mainly about the communication about the design content. So, it is logical that we found most barriers and enablers on the actor level. From a psychological point of view can be added that actors forget planning- and progress problems and problems concerning the design content are remembered easily.

During the two real time case studies done, we could not (and did not want to) influence the content of the interviews. We interviewed the actors about the frames constructed during their meetings. At this product design project, as well as in the other case, communication about tuning between the processes of the different departments seemed to be more important than tuning about the design content. More strongly, the management advised against communication about the design content in meetings. Therefore, more frames were constructed on the project level and we found more barriers and enablers on this level.

Despite, we did not count the exact duration of the subjects communicated, the proportions of kinds of communication seemed different than in the study of Olsen et al. [24]. Apparently, the tuning between the tasks of the actors from different departments cost more time that in the study of Olson et al. at the cost of content related communication. The consequences of this become apparent looking more closely at the themes.

First, there is communication between the technical sub systems (theme 1). This communication is both procedural as well as content related. The team observed had lack of shared understanding about content related aspects on a conceptual level. To improve this kind of communication it is important to have (in future projects) a strong System Engineering group with product-architectural knowledge, from the beginning of the project until the end. This System Engineering group has to make all interfaces clear and need to integrate knowledge on different levels and knowledge bases of the project. The System Engineering group should be able to think conceptual, but must also be able to understand (detailed) information from the different technical subsystems to be able to make a good decision. The System Engineering group should also have the power to make all decisions concerning the integration of the technical subsystems.

The second type of communication is the external communication between the team observed and the consortium they are in (theme 2). In this product design project, the main problem with this interface was the involvement of Maintenance early in the project. This problem is comparable with the involvement of production in the development process. Both concern (for efficiency reasons) the involvement of a discipline earlier in the process than they have to do their actual job. An engineering law says that during a development project 80% of the decisions are made during the first 20% of the project time (80/20 rule). This shows the importance of involving Maintenance and Production (with respect to the content) in the early stages of the project. Only then, they can give advice on the important decisions, because involving Maintenance and Production in a later stage will only solve cosmetic problems. From literature, we know that the interface between Development and Maintenance or Production causes difficulties, because there is no shared understanding between the two disciplines. [24], [19]. In this product design project, the involvement of the Maintenance organization was only procedural, while development needed content related information to be able to make engineering decisions favorable from a Maintenance point of view. Maintenance could not give that information, because they were not used to think as

Developers do. In order to create shared understanding between these two disciplines the actors should pay much attention to what information is actually needed (problem definition). Also the format of information exchange between the two disciplines should be made explicit and applicable for both. Finally, there should be a clear planning, in which the actors visualize the main activities and dependencies.

The third type of communication is the external communication between the team observed and the outside world (theme 3). The product design team needed communication with parties like i.e. the Fire Brigade. The main problem here is the fact that the outside world has most of the time a customer role instead of a cooperative role. They do not see benefits for cooperation and they are not used to cooperate. However, to do an efficient product design project, the company needs them, because in the end the have the power to reject the new product when it does not fit their needs. Therefore, the company has to find ways to get information from these parties in future projects. This is difficult in many product design projects since the real customer, or user is unknown at the time of development.

This is also the case in consumer industry. It is difficult to involve consumers early in the product design process, because they are not able express what kind of products they want in the future. Besides, they talk other language than developers do [25]. Market researchers use creativity techniques like brainstorming, brain drawing and storyboard making to involve future users into the development process. Early involvement of the customer in an advisory role, using the techniques mentioned, will have a positive affect on both product quality and will decrease development time in future product design projects.

To organize the external communication on all levels a communication infrastructure is set up (theme 4). The written communication infrastructure in this development project is highly formalized. It is so much formalized that actors think in documents as deliverables. In this product design project, they called this phenomenon the paper tiger. This paper tiger make it possible to control the quality of the process followed, but it makes the process also inflexible. Actors consumed much time is to do all the paperwork. Of course in other development projects quality management is an important issue, but it is never seen, by the customer, as important as the product, which makes this development project rather unique.

The content of theme five is related to this aspect. Theme 5 is more content driven and is about implementing new processes. The two new processes are V&V and RAMS. Both are quality related items. Separating V&V and RAMS from the sub teams, by setting up new sub teams, hampers integration of V&V and RAMS in the separate development processes of the technical subsystems. The decision to do this is perpendicular to the integrated product development theory which subscribes all activities together should form one overall process [26].

However, from the perspective of the project board it is an understandable they separated these processes. The V&V and RAMS processes are of vital importance to succeed in the product design project. Implementing such important procedures in the development processes of the technical subsystems is hazardous. The actors did not have any affinity with it and knowledge about it. Therefore, the V&V and RAMS process might have become underexposed.

Companies do often separate important processes from the main process, but this is not so often a success. An example in another field is the wish for sustainable development. Many companies did research about how to make their products more sustainable, but they did only succeed really when the approach was done integrally during the total product development process. [27]. In the earlier study of Kleinsmann and Valkenburg about the achievement of shared understanding, there were also problems implementing a new aspect in the development process [19]. In that study, it did not concern the implementation of a new process, but it concerned the implementation of new technology. Looking at the problems between the implementation of a new technology and the implementation of new processes, the problems with the creation of shared understanding appeared to be the same. In both cases object worlds and thought worlds hamper effective communication and there are difficulties is planning and monitoring the project. This finding is in line with the innovation theory which says that every abrupt change causes difficulties and asks a lot of effort from the actors involved. Solutions can be found by explicitly making the new procedure an integral part of the development process. This takes time. New interfaces must be made clear. And actors should be trained about the new process in a way they are able to interact with the specialists.

8. Conclusion

In this research project, we were interested in factors that stimulated or undermined the creation of shared understanding. In an extensive case study in practice, we detected barriers and enablers for the creation of shared understanding. We collected data by observing meetings and interviewing actors about the frames they constructed during meetings.
The data were analysed according to the learning history method, which proved again to be an efficient and transparent way of gaining insight in product design projects. It shows not only the research variables of this project, namely the enablers and barriers on different organisational levels. It also reveals the relation of these variables with the content of the project. This enables us to indicate the themes, showing issues that indicate problems in the project. The themes are for the company a reflection on their project, from wich they can learn. For researchers the themes are useful, because they bring the specific barriers and enablers on a more abstract level. This makes it possible to compare their topics to similar studies or to comparable situations.

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